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EDITOR
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University of Toronto, Toronto.

ASSOCIATE EDITORS

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Director of the Dominion Astrophysical Observatory, Victoria, B.C.

J. PATTERSON
Director of the Meteorological Service of Canada, Toronto

R. MELDRUM STEWART
Director of the Dominion Observatory, Ottawa

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MAKING THE WORLD SAFE BY SEISMOLOGY *

By Ernest A. Hodgson

WHEN one, who is concerned chiefly in the study of earthquake phenomena, receives an invitation to speak in public, he must assume that his subject is expected to be in some way related to the science of seismology. That invitation having been received from a component Club of the Montreal Amateur Athletic Association, it is a little difficult to discover the region of common interest between seismology and athletics. When, in addition, the speaker knows nothing of the Club, other than that it is called the "Wheelsmen", he is led to speculate on the further limitations, within the athletic field so to speak.

The problem of effectively discussing a subject, before an audience to whom it is only casually or remotely of interest, is one which presents itself with monotonous regularity, week after week, to the many preachers of our land who, someone has said, work at their jobs "to beat hell". Their solution is simple; they choose a text. It serves them as a theme song serves a musical comedy, unifying their presentation and even helping to amplify it when needs be. It affords a point of departure and a place where, from time to time, they may alight for rest, as the ark served Noah's dove. Alas if sometimes a weary pew-holder concludes that the waters have indeed receded.

Such a device seemed desirable under the present circumstances. The text chosen is the title, "Making the World Safe by Seismology". Let us hope that it will serve to unify and not to amplify this talk.

* Presented before "The Wheelsmen", the service club of the Montreal Amateur Athletic Association, on Thursday January 11 1934.

It will be used as a point of departure and we shall alight on it from time to time to re-orient ourselves for further brief excursions.

It is an unfortunate circumstance that science, so called *pure*, is looked upon askance to-day by many people. They deplore the expenditure of time or money for scientific investigations other than those which they term *practical*. The present generation seems to regard the terms *pure* and *practical*, whether applied to science or anything else, as being mutually exclusive. That which is pure is not considered practical, and to be practical is to be impure. As a matter of fact, these fields in science overlap very widely. Some of what is called science is neither pure nor practical, nor is it scientific; but none is either pure or practical exclusively. Nevertheless, there is a utilitarian standpoint from which one may view any science: what does it contribute to-day to the immediate well-being of mankind? Our title, or text, has been chosen with a view to limiting the discussion to the utilitarian aspects of seismology.

About twenty years ago, someone, skilled in the art of propaganda, camouflaged the basic cause of a titanic debacle by coining the phrase, "Making the World Safe for Democracy". The war was fought and won and now we face the desperately pressing problem of making Democracy safe for the world. Whenever an earthquake occurs in a district where such visitations are not common, a number of pseudo-scientific propagandists endeavour to take advantage of the high tide of public interest in earthquakes to launch certain of their pet schemes. The unethical and heinous nature of such a procedure could be even more clearly pointed out were it not that, in the same circumstances, the same advantage is being developed by even the most conservative investigators. The title, "Making the World Safe by Seismology", rings the changes just a little on the propaganda slogan, "Making the World Safe for Democracy". It is true that it introduces a consideration of the commercially and socially valuable aspects of seismological study, but be assured that care will be taken to restrict the discussion to those benefits which are real and attainable, even if, as yet, they are not quite, in full, attained.

The relative interest taken by the public in different earthquakes occurring from time to time is measured very closely by the relative

space accorded them by the newspapers. This is, however, no true indication of their absolute relative importance from any viewpoint, whether it be that of the student of seismology, the engineer, or the insurance adjuster. When news is scarce the occurrence of a tiny quake assumes the importance of the arrival of the new, young, and handsome curate at the ladies' sewing circle. But an earthquake of major intensity, especially if it occurs in a region where no damage is done, becomes second or third page, quarter-column stuff on, say, election day. The news pressures from other sources being equal, however, the space accorded an earthquake by the newspapers is roughly proportional, not to its absolute intensity, but to the damage it causes life and property. Many earthquakes of first magnitude occur where there is no property damage and where there are no lives to be lost. Such earthquakes do not receive much attention from the general public but their study has very important utilitarian as well as scientific value.

Undoubtedly, earthquakes are a menace and a danger. We cannot prevent their occurrence. How then can seismology make the world safe from earthquakes? There are few dangers to which man is subject, which are not greatly minimized when viewed from every angle and studied with painstaking care. Wine and Women may be cited, almost proverbially, as being beyond the operation of this law, but earthquakes undoubtedly come within its purview. Seismology will make the world safer, if not safe, through its close study of earthquake phenomena.

The first outstanding line of research, which we shall consider as tending to make the world safe from earthquakes, is that of cataloguing them consistently and regularly, recording their distribution in space and in time. If we know the distribution of earthquakes geographically and chronologically over a long period of the past, we are in some measure able to determine at least *where* they are likely to occur again. In such deductions, the matter of time is more uncertain than is place, though each has its peculiar limitations as will presently appear.

Until sensitive and continuously-recording instruments were invented and used, the detection of earthquakes at great distances was out of the question. At a thousand miles or more the largest

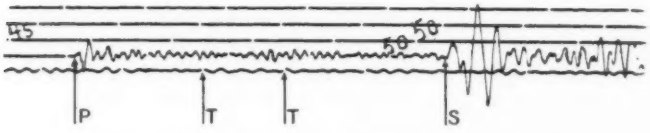
earthquakes cease to affect our senses. The increasing use of sensitive instruments in astronomy and meteorology revealed the fact that slight disturbances affected them at irregular intervals. Systematic inquiry as to the source of these disturbances began in England, France, and Germany as early as 1865; shall we say seventy years ago. About this time, a group of English seismologists began to work in Japan,—Milne, Gray, Ewing, Perry, and Knott. The times when severe earthquakes occurred in that seismically-active country began to be a matter of record and these times were found to coincide roughly with some of the instrumental disturbances in Europe. In 1889, von Rebeur-Paschwitz, working at Potsdam and Williamshaven, set up an instrument known as a horizontal pendulum, which was arranged to continuously record earth tilts of small magnitude. He was interested in a study of earth tides, but his records showed these same disturbances from time to time. He established, definitely for the first time, the correlation between earthquakes in Japan and disturbances on a horizontal pendulum in Germany. Thus, only about forty-five years ago, were the first earthquake records obtained.

These same records obtained at Potsdam showed that two sets of tremors were registered, the second set arriving some minutes after the first.* Further study served to identify these as being caused by energy which left the epicentre of the earthquake at the same instant but which was transmitted by two different properties of the earth, and at different velocities. In the words of the physicist, the earth is an elastic solid. All such bodies transmit vibrations in these two ways and, in the case of the earth, the distances are so great that the separation of the two sets, or "phases" as they are called, is quite marked. This separation is greater as the distance from the station to the epicentre is greater. It thus became possible to find the separation of the phases for different distances for an earthquake whose epicentre and time of occurrence were known. In this way a set of tables was evolved. From these tables the distance could be read off corresponding to the separation of the phases on the record of any earthquake.

*See P and S of the figure below. The breaks in the line, as at T, T, indicate exact ends of minutes.

Thus, from the records of one station, it was found possible to determine the distance from that station to the epicentre, much as one estimates the distance to a bolt of lightning by timing the interval from flash to thunder. In general, if the distances from three stations are known the position of the epicentre can be determined, even though it lies in an inaccessible region, beneath the sea or in the polar latitudes.

Von Rebeur-Paschwitz and Milne proposed a world-wide distribution of earthquake stations, equipped with seismographs of suitable design. It was Milne, however, who was responsible for



RECORD OF MEXICAN EARTHQUAKE, AUGUST 16, 1931.
Distance from Epicentre, 1800 miles.

accomplishing the plan. Some of the later installations were in Canada, one being established at Toronto in 1897, and one in Victoria in 1898. The instruments at Ottawa were first operated in 1906, but not through Milne's direct agency, he having by that time retired to the Isle of Wight where he compiled his catalogues of earthquakes which, since his death in 1913, have been carried forward under general international co-operation.

The time and place of practically all large earthquakes which have occurred within the past forty-five years are now recorded. It is known that certain areas of the earth are actively seismic—the borders of the Pacific Ocean, the north mid-Atlantic up to Iceland, the Mediterranean, and the highlands of Asia. But these facts were known, in general, before the seismological services were inaugurated. The seismic areas are now more sharply defined—that is all. The important fact that is being borne in upon seismologists is that no place in the world can be declared with certainty to be earthquake proof. Our instrumental records go back

for such a very short span in geological time that, in the case of places like British Columbia and the western United States which have been settled only within the past half century, more or less, the seismic history is not known in measure sufficient to permit even an approximate prediction of their seismic future.

Within the past eight years no less than three very severe earthquakes have occurred in regions believed immune. Only one of these happened where damage could be caused. This was the Newfoundland, or Grand Banks, earthquake of November, 1929, when an earthquake caused damage to Atlantic cables to a total of more than a million dollars. It can only be said of any place that the longer it is since the last earthquake occurred, the shorter will be the time till the next. Meanwhile, seismology continues to amplify her catalogue data which will make the world safer from earthquakes to the extent that the areas marked as seismic are avoided where it is possible.

Unfortunately, some of the seismically-active regions cannot be avoided. A second type of seismological research is being carried forward, designed to make these parts of the world more safe than they would otherwise be. Two facts stand out prominently. In the first place; it has long been known that one of the reasons why earthquakes have caused so little damage on this continent is because the places which could suffer damage have been so widely scattered. In the second place; it has been learned that certain types of construction can come through an earthquake practically undamaged, while others are veritable earthquake traps. Moreover, the added cost of providing for earthquake forces is only a small part of the total cost. In the case of one large apartment house recently completed in San Francisco, the extra cost of this provision was less than two per cent. of the cost of the building; and when the reduction in insurance rates, etc., was taken into account it was found that this added cost had been absorbed and the whole transaction showed a net gain of over two per cent.

The outstanding object lesson, bringing home the two facts stated above with striking force, is found in the recent Long Beach earthquake of March 10, 1933. Two years before, a prominent consulting engineer and insurance man—John R. Freeman—pub-

lished a book on earthquake risks. In it he compiled a table showing all the losses due to earthquakes (exclusive of fire) incurred in the United States and Canada during the past 100 years. As, before that time there was little to damage, it may be taken that his total of $40,000,000 shows the loss for all time in the two countries mentioned. The Long Beach earthquake was really a comparatively small affair but it happened to strike a city. The total loss was estimated at $50,000,000; twenty-five per cent. more than all the loss in all Canada and the United States for all time! Surely this serves to illustrate the first fact that, as the country becomes built-up, earthquakes are bound to cause more damage because there is more to be damaged.

But the illustration of the second fact is even more striking. In spite of all this damage—not to mention the loss of over 100 lives—it is a fact that every building which was constructed with the reasonable earthquake protection factors incorporated in it was practically undamaged, standing quite intact while its neighbours collapsed. Need more be said? Seismology can make the unsafe places of the world safe from earthquakes by indicating proper building design. Moreover, seismology has already shown how to arrange the water supplies in seismic areas so that the tragedies of San Francisco and of Tokyo need not, and probably will not, be repeated though each of these places will probably suffer earthquakes at some time in the future.

Alighting once more on our text, let us read *world* as an adjective and *safe* as a noun; and for a moment or two let us consider how seismology has been attaining an entrance to, or *making* if you will, the world-safe in which treasures of minerals and oil have lain so long inaccessible. It has been found that earthquakes generated by explosions and registered by seismographs at distances up to ten miles can be made to reveal the nature of the subterranean structure and indicate the location of oil and minerals.

For example: down in the Gulf States, there is a curious geological structure known as the salt dome. The layers of sedimentary rock near the surface are pierced here and there by gigantic plugs of rock salt. The effect is much the same as if a thick bolt were forced nearly through an old type fabric tire. The shredded

oil-bearing rocks yield their store and a pocket is formed on the flanks of the salt dome. The width of a dome may be only a few hundred yards but it is often more than a mile. The top seldom reaches the surface and no indication of it can be seen. So often are these domes the site of oil deposits that one of them, located but unexplored, has been estimated to be worth $100,000.

So there they are, hundreds of domes beneath the surface. Where can wells be drilled with the chance of hitting one? Seismology comes to the rescue. The explosion tremors travel much faster in rock salt than in the sedimentary rocks. Thus a blast set off at any given point may be picked up by a ring of seismographs at distances up to several miles. The normal travel time for each path is compared with the recorded travel time. Should any recorded interval be less than normal it may be inferred that the path crosses a salt dome—a new dome has been discovered.

Prior to 1924, only forty-three domes had been discovered by geology or accident over a period of a quarter of a century. From 1924 and up to and including 1929, sixty-four more were discovered by seismic methods alone. Moreover, once found, the dome may be quite cheaply outlined and mapped from the surface by seismic methods and the most likely point chosen for sinking a well.

When it is remarked that salt dome structure is only one field in which seismic exploration methods may be used it becomes apparent that the case is established that the world-safe, stored with priceless treasures of the ages, is indeed being made accessible by seismology.

In conclusion, let us be reminded that, whether we considered seismology as making the world safe or as making the world-safe, we dealt (and dealt in very sketchy fashion) with the utilitarian aspects of the subject, only. Locked up in the world-safe, deep in its never-to-be-probed depths, lie treasures of knowledge which are greatly coveted. If we could know what materials are in the depths of the earth and how they are distributed there, we could check the various theories as to how the world was formed. Cosmogony is a fascinating field of scientific philosophy, but, unless it can be checked by reference to nature, it runs wildly rampant.

Time fails for an exposition of the way by which seismology

affords this desired check. Suffice it to say that earthquake waves may be registered on seismographs after having penetrated the earth to any and all depths. It is possible, from a study of these records, to determine the maximum depth of penetration corresponding to any given epicentral distance and to ascertain the velocity of the earthquake wave at that depth. The laws by which this velocity varies with depth afford a great deal of information as to the structure of the earth, and this, in turn, keeps the philosopher who formulates theories as to how the world came into being and how changes now take place in its surface features, from indulging in flights of fancy too fantastic.

Thus we see that seismology helps to make the world safe and to make sane our conception of its origin and its structure.

Dominion Observatory,
Ottawa, Canada.
January 11, 1934.

STAR-HUNGER

I know among the golden Pleaides,
Or in the warmth of far Arcturus' light,
There must not be the crass, dark miseries
Which curse mankind in Earth's deep, tragic night.

In that white glow so radiant and so fair
Which Rigel sheds resplendently above,
Surely, ah surely, no marauders there
Rob life of hope and faith and deathless love.

Unhappy Earth, with self and lust supreme,
How have men blighted what wise nature gave;
How have men crushed the vision and the dream
And left no choice—want, poverty, the grave!

I know that where Orion glows and smiles
There must be justice, hope and plenty spread;
My deep heart tells me that those starry aisles
Know not Earth's tragic suppliance for bread!

My soul has grown impatient for release,
Sick to its core with wrong, injustice, greed;
Surely, ah surely, there is Love and Peace
Where great white stars, like gods, in silence speed!

Algol or Sirius beckoning through the night;
Polaris or Antares, worlds apart—
Any far speck, unutterably bright,
Is kindlier, friendlier than Earth's frozen heart.

And after this wild orgy of despair
Where life's ideals by mammon's hand are stilled,
In some star's fire-mist, infinitely fair,
Man's hungry heart shall find its dream fulfilled.

BERT HUFFMAN.

Cheadle, Alta., January 1, 1934.

THE ELECTRONIC TELESCOPE

By F. C. Henroteau

DIRECT optical methods have always been used to interpret the wonders of the universe and even a few years ago it might have been argued that these methods alone could solve the problems involved. Take as an example the one hundred inch Mt. Wilson telescope provided with the latest photographic equipment and one naturally assumes that the zenith of observational astronomy has been attained.

To obtain spectrograms of far away nebulae, hours of exposure are needed and while recognizing the extraordinary work which has already been performed, our knowledge of the planets is still elemental, as we all know. At this present time in order to demonstrate the possibilities already in view, larger and still larger telescopes are imperative. However, owing to the unstability of the seeing due to the earth's agitated atmosphere, the difficulty of construction and the almost prohibitive cost, a practical limit must be reached in the use of these instruments as we know them. By taxing the ingenuity of its designers a two hundred inch telescope is considered feasible but the construction of a two thousand inch aperture instrument, I am certain you will agree with me, is beyond the wildest dream of the most optimistic scientist.

Naturally I am not advocating the building of a two thousand inch telescope but I am considering the plan of an electronic telescope which will eliminate more unwieldy and involved processes. Electrical instead of optical amplification with the consequent tremendous possibilities.

It occurred to me that the image of a celestial object can be focused, not on a photographic plate, but on a particular electric plate out of which will flow a current modulated by the picture, a current which will be amplified millions of times by the use of three-electrode valves to reproduce upon an adjacent screen an image both large and bright. One can easily comprehend that this means a definite farewell to long exposures in astronomical photography.

Such an instrument is no longer a matter of conjecture, and encouraged by months of research in the laboratories of the General Electronics Corporation in Boston, we feel that its construction is both practical and reasonable.

THE TRANSMITTING TUBE (IN THE AUTHOR'S HANDS).
In the centre of the tube is the screen on which (for example) the image of a stellar spectrum can be focussed; in the present instance this screen is coated wth 160,000 silver dots to the square inch, all caesium sensitized. At the extreme left of the tube is the cathode ray gun and the white part in the right hand is the silver coating which constitutes the anode.

Several years have elapsed since I realized that the generally accepted idea for demonstrating television must be discarded, although this idea had met with some measure of success in the hands

of John L. Baird in England, Mihaly in Germany and at the Bell Telephone Laboratories in the United States. Indeed, even using the most sensitive photo-electric surface the largest number of elements which can be transmitted by this method is 10,000 or so; this is, you understand, a number much too small to obtain any sort of definition at the receiver.

Now a radically different system seems far more simple and practical. It appears to me that if all the elements of a view accumulate electric charges simultaneously and these charges act one by one to produce a flux of current in a single transmitting channel, this would be the evident solution.

Applying this idea astronomically, the image of a celestial body is focused on a plate composed of a large number of mutually insulated photo-electric elements which thus accumulate positive charges controlled by the light values which strike them. At the same time these elements in successive small groups are very rapidly scanned by an extremely thin beam of cathode rays of constant intensity. This produces the ejection of secondary electrons from these elements while simultaneously forcing electrons into them. Now this action is such that each element is brought to an original equilibrium potential and as a result, the charges accumulated by the image are released to form a modulated current directed to the amplifier and transmission channel.

Such a model has been constructed for television purposes and we have produced transmitting screens with as many as 160,000 photo-electric caesium sensitized silver dots to the square inch and we have produced a scanning spot of electrons as asmall as 0.016" in diameter. It gives pictures at the receiver approaching the quality of the cinema. However, 160,000 silver dots to the square inch with a scanning spot 0.016" wide, although giving fine enough detail for television pictures is still much too coarse for astronomical applications. Images formed at the focus of a telescope, even of great focal length, cover small areas.

But there is new hope. During recent experiments, by an entirely new process I have succeeded in covering very thin mica plates 4 x 5 in. with 25,000,000 pure adherent silver dots to the square inch, 500,000,000 dots altogether, all of uniform size and

uniformly spaced! These silver dots are finer than the grain of the finest photographic plate made at present, and by a new method, I use a scanning spot of electrons as small as necessary, 0.0001 in. or smaller. By lengthening the scanning time to several seconds, the frequency of the output current will be reduced and no difficulty will be experienced in its amplification.

The caesium surface of the photo-electric elements is so sensitive that it emits a current in vacuum of twenty micro-amperes per lumen of light falling on it. In this case a rough computation shows that the image of a star of magnitude 13.5 at the focus of a sixty-inch telescope, if scanned in 0.1 second would produce an output current of the order of 10^{-16} amperes; if scanned in ten seconds the current will be of the order of 10^{-14} amperes. The spectrum of a star of magnitude 3.5 at the focus of an ordinary stellar spectrograph attached to a 15-inch telescope, such as that of the Dominion Observatory in Ottawa, with a scanning beam of electrons sweeping it in two or three seconds, would produce an output current of the order of 10^{-10} amperes, which can be readily amplified.

In this way a stellar spectrogram which formerly took thirty minutes to obtain with the Dominion Observatory equipment, would at present only take a few seconds.

Personally I see no legitimate obstacles to unprecedented results by the telescope of the future. No doubt there are many who do not agree with me in the least but nevertheless, it must be admitted that here is one of the most fascinating problems of to-day and for once we have the advantage, as I said before, of having already accomplished successful experiments.

THE NEW TELESCOPE MIRRORS*

By Henry Norris Russell

THE heart of a reflector telescope is the mirror and it is here that troubles begin, for no ideal substance for the construction of optical mirrors has yet been found or is in sight. The perfect material, which Dr. Anderson in an imaginative mood has called "mirrorite," must be rigid and permanent but not brittle or too heavy; must have a vanishingly small coefficient of expansion and conduct heat freely so that it shall not be distorted by temperature changes; must have a very high reflecting power for all wavelengths from the extreme ultra-violet to the infra-red; must be capable of being worked to an exceedingly accurate figure and retaining it for years without distortion or after-effects; and must take a high polish and retain it free from tarnish or stain under all the vicissitudes of the observatory or the laboratory. Such a miraculous combination of virtues is too much to hope for; we must be content with an approximation.

When it comes to metal mirrors, nothing is yet available that is much better than the speculum metal used by Herschel, an alloy of tin which takes and retains a fine polish but unfortunately is almost as brittle as glass. It is still generally employed for diffraction gratings and some other purposes, but for telescopic use it has the great disadvantage that any tarnish on the surface cannot be removed without re-polishing, with the accompanying danger of spoiling the accurate figure of the surface. Modern practice therefore tends almost exclusively toward glass mirrors.

Properly annealed glass is admirably rigid and permanent and can be cast in large masses. Its coefficient of expansion is lower than for metals and may be much reduced by the use of special glasses of the Pyrex type, and it takes and retains an excellent polish. Fused quartz is still better, but has not yet been successfully obtained in really large disks.

*A portion of the article by Professor Russell in the *Scientific American* for February, 1934.

But the reflecting power of a bare glass surface is ridiculously low, so that it is of no use till it has been coated with a metallic film so thin that its presence does not spoil the shape of the surface. For many years the standard coating has been of silver. This can be easily deposited on a clean surface by chemical means. The amateur in his first trial may think the process complicated, messy, and anything but easy, but in expert hands it is all in the day's work. An imperfect coating can be dissolved off in a moment with nitric acid and resilvering begun.

When the silvering solution has been washed off with distilled water the surface is dim with more or less of a "bloom," but this is removable by ordinary polishing.

A fresh silver surface has a very high reflecting power for visible light—fully 90 per cent.—but it has serious disadvantages. First, it is soft and easily scratched. Even polishing with the finest jeweller's rouge produces microscopic scratches which scatter light and make it hard to observe faint stars near bright ones. Secondly, it is very liable to tarnish. Even in the best atmosphere a silver coat deteriorates badly and has to be replaced in from six months to a year, and there is an important loss in reflectivity before this. Third, and most serious of all for the spectroscopist, the reflecting power of silver falls off very rapidly in the ultra-violet. Near 3,100 angstroms it is only 5 per cent.—hardly more than for bare glass. Indeed, a silver film is almost transparent for such light and serves as an excellent colour filter. For shorter waves the reflecting power gradually increases but is still low. On this account it is practically impossible to photograph the spectrum of a star with silver mirrors in the region below 3,400 angstroms, and much detail of great interest lying between this and the limit set by atmospheric ozone at 3,000 angstroms is inaccessible.

A better metallic film is much to be desired, and one with almost ideal properties has recently been found. It is of a familiar but most unexpected composition—aluminum!

We ordinarily think of aluminum as a greyish metal, and few of us have ever seen a highly polished surface—for if prepared in the ordinary way it tarnishes very rapidly. Aluminum, indeed, is one of the most active, chemically, of all the metals and no one would have expected it to give permanent mirror surfaces.

Success of course depends on finding the right way to put the aluminum on the glass. It is done by evaporation in a vacuum. The metal has a rather low boiling point under reduced pressure and there is no great trouble in volatilizing it, but the form in which it comes down depends enormously upon the vacuum conditions. In a partial vacuum, at a pressure of about 12 mm., Dr. Pettit finds that it invariably deposits in a finely divided form which makes a dead black coating. Many other metals—as different as gold and zinc—do just the same, and the process is useful to *blacken* small pieces of apparatus. At lower pressures—say 1 mm.—aluminum deposits as a fine white powder. But if the pressure is kept exceedingly low, so that the separate atoms of metal which evaporate from the heated filament fly clear across the vacuum chamber without hitting any gas molecules on the way, they condense on any *clean* surface in the form of a brilliant, lustrous, polished mirror.

One might fear that when air was admitted, this coating would oxidize and be spoiled, but it covers itself with a uniform, transparent, and almost infinitesimally thin film of oxide and suffers no further change. This film is what makes the process valuable. Aluminum oxide is one of the hardest known substances, appearing in nature as corundum (emery) or in its precious forms as ruby or sapphire, and the tenacious coating which automatically forms on the surface has extraordinary protective powers. The film can be washed with soap and water—ordinary soap and water—without damage. Indeed, this suffices to clean off any dust or faint bloom, and no polishing is necessary. Its chemical and mechanical resistance is amazing. A few days ago the writer saw a young physicist take a brilliant aluminum-on-glass mirror and pour concentrated nitric acid over it. A silver mirror would have vanished in the twinkling of an eye, but this one was utterly unaffected and, when washed under the tap and dried with a soft paper handkerchief, was a little brighter than before. Then came a still more amazing test—a strip of sticking plaster was laid on the mirror, rubbed down and pulled off from one end, leaving no trace of injury! These films can, however, be dissolved by caustic alkali solutions, which is convenient for removal of an imperfect attempt.

No one knows yet how long the film will last without tarnish under good conditions—the process has not been invented long enough—but no serious trouble has appeared in a year's service.

The reflecting power for visible light is about 85 per cent.—slightly less than for new silver but better than silver even slightly tarnished. In the ultra-violet it remains above 80 per cent. as far as 2,500 angstroms. With aluminized mirrors and quartz prisms and lenses, the stellar spectrum between 3,400 and 3,000 angstroms should now be easily observable.

No one who has seen the new mirrors doubts that the future is theirs. At the Mount Wilson Observatory, for example, all the auxiliary mirrors of the great telescopes—some of them 30 inches in diameter—are being treated by this new process, by co-operation with the California Institute of Technology in whose laboratories a special vacuum apparatus has been developed, capable of taking things up to this size. The troublesome problem of getting the glass surface perfectly clean has been solved and the process is "in production".

The amateur telescope makers—of whom many, it is hoped, may read this—will naturally inquire: What chance have we at this great improvement? The individual amateur would probably find the process impracticable. The construction of an aluminizing apparatus big enough to hold a good-sized mirror, vacuum-tight up to the requirements of an X-ray tube, and provided with the necessary devices for exhausting the air and volatilizing the aluminum, involves considerable time and cost, and its operation demands a skilled technique acquired only after a good deal of laboratory experience. The average telescope maker can hardly hope to set up so elaborate an outfit, but there seems to be no reason why a co-operative effort might not succeed. Someone with special interest in the problem might tackle it and, if successful, might be in a position to supply his brother astronomers—amateur or even professional—with this new and admirable advantage.

THE UNIVERSE WE LIVE IN*

By R. Meldrum Stewart

MAN is by nature an inquis'tive animal. Or perhaps we should say, more euphemistically, that he is blessed with an ardent curiosity, leaving the more plebeian term inquisitive to be applied to our cousins and other more distant relatives who stand lower in the scale of evolution. In childhood—in infancy even—we are curious about our immediate surroundings; a little later our curiosity extends itself to our more distant environment—to neighbouring towns and cities—to more distant and foreign countries—to unexplored lands in the inaccessible regions of the earth—and even beyond, to other worlds and to distant and unattainable regions of space. Or perhaps it directs itself to our neighbours—to the study of humanity—to the past history of the race—to researches on the origin of life and of the world—to speculations on the future and all that it holds for good or ill.

We scientific people, at all events, like to believe that a properly guided and properly controlled curiosity is the highest gift of man. The uncontrollable urge to know just for the sake of knowing—has been the guiding star of discovery all through the ages. No worthwhile advance in pure science (as distinguished from applied science) has ever been made with a practical end in view.

Always it is the urge to know why, merely for the sake of knowing, that is the mainspring of discovery and advance in knowledge. Can anyone believe that a Newton or a Maxwell either foresaw or cared that his work would be the basis of all practical applications of mechanics or electromagnetism? or that Hertz, the discoverer of wireless waves, had any practical ends in view? Call this spirit of scientific curiosity a selfish one if you will. The fact remains that it is one of the most fundamental things in human nature, and that without it the real fundamental discoveries, which form the foundations upon which practical science is built, would never have been made.

*Broadcast through the Canadian Radio Commission, December 8, 1933.

And that is why I, as an astronomer, a follower of what is often called the most impractical of sciences, venture to address you to-night on such an abstract subject as the universe. It is true that astronomy has vital practical applications, and the two Canadian observatories of the Department of the Interior, at Ottawa and Victoria, are fully alive to that fact. But they would be recreant to both the principles and the traditions of astronomy and of science in general if they did not apply themselves as well to the advancement of pure knowledge for its own sake. This address, however, is not a description of the work of the Canadian observatories, but a short account of the present state of knowledge about the universe.

What, then, do we know of the universe? Thanks to the astronomers of the past, we no longer believe that the earth is the centre of all things, supported by a gigantic elephant or tortoise, surrounded by unexplored and un-navigable seas, and that the sun, moon, and stars revolve around it daily from east to west, fixed in a revolving firmament a few miles distant. But there are still many things we do not know, some, perhaps, that we may never hope to know.

We do know something of the size of the universe, at least that part of it that we can see with our most powerful telescopes. Our knowledge of this is founded on the familiar surveyor's method of measuring a base-line and observing from its ends the direction of a distant object. When we have thus measured the distance of the sun, some ninety-three millions of miles, we take advantage of the earth's motion in its yearly orbit around the sun to obtain a longer base-line. In fact we have only to wait six months to have the earth carry us from one end to the other of a base-line a hundred and eighty-six million miles in length. And by the direct use of this we can, by very refined observations, measure the distances of many of the nearer stars. By this method we gather that the earth is only one of the smaller planets that constitute the family of the sun. Jupiter, the largest of these planets, has ten times the earth's diameter and a thousand times its bulk; the sun itself surpasses the earth a million times in size, and our little planet could be easily swallowed up and lost in one of the spots that occasionally mar its surface. We find that the whole solar system occupies only an

isolated spot in space, separated by almost inconceivable distances from its nearest neighbours among the stars, which are themselves located at distances from one another of the same order of magnitude. We find also that the sun, which looms so large in its own family, is only an average, or less than an average star, and that there are others that surpass it thousands or even millions of times in bulk. In fact there are stars so great that, if the centre of one of them were made to coincide with the sun, we on the earth would still be many millions of miles inside its surface. Already we begin to realize our own insignificance.

But as yet we are only on the threshold. Our tapeline has extended only to a few of our nearest neighbours. What further lies beyond? By the application of other methods, with the details of which I shall not trouble you, but which are all standardized and calibrated by the familiar surveyor's method, astronomers have contrived to measure, with more or less accuracy, the distances of most of the typical celestial objects revealed by our largest telescopes. It is found that when we penetrate into space to a distance of fifty or a hundred thousand light-years—a light-year being the distance travelled by light in a year, some six millions of millions of miles—the stars begin to thin out on all sides; we have reached the bounds of the Galaxy or Milky Way, our own local "universe". To this galaxy belong all the stars we can see with the naked eye, and most of the stars brought into view by the telescope. The more distant parts, though not the *most* distant, can be seen as the familiar band of hazy light stretching across the sky, and known to us from childhood as the Milky Way. This is in the form of a flat disc, probably with spiral arms and many outlying irregularities, and with a diameter many times its thickness.

But we are not yet at the end. Far beyond this, across vast regions of empty space, lie still other galaxies, many of them probably comparable in size and importance to our own—the spiral nebulae. These have been discovered in their thousands and tens of thousands, stretching as far as the limits of our telescopes have yet revealed, and who shall say how much farther? The most distant yet glimpsed is estimated to lie at a distance of a hundred and fifty million light-years—a distance that, in miles, would be

expressed by the figure nine followed by twenty ciphers—an extent that, even expressed in figures, is beyond our powers of comprehension. What lies beyond we shall have to leave to the future to reveal.

Having thus, in thought, explored the bounds of the universe, we set out upon the return journey, threading our way through empty space from galaxy to galaxy, passing, among the nearest outposts, the Andromeda nebula, then after an interval, when nearing our own galaxy, the globular clusters, the galactic nebulae, our local cluster, finally—if we can find it—the solar system and the small planet upon which we dwell, with all its repercussions of portentous human events.

On the other hand, as well as the almost infinitely great, we find throughout the universe the almost infinitely small. The most distant star is built up of the same elements we find upon the earth—the same atoms and molecules, the same proton and electron, and no doubt also the latest born of the physicist's playthings, the neutron, the positron and the deuton. That magical instrument, the spectroscope, reveals the most marvellous unity everywhere, but—and this is the important point—in the stars we find our familiar forms of matter under conditions of temperature and pressure that can never be attained in terrestrial laboratories. And that is why the new science—astrophysics—has assumed within the last generation an ever-increasing importance and has become so closely wedded to theoretical and practical physics. It is true that in the celestial laboratory we can not control the conditions of our experiments, and the interpretation of results becomes more difficult. But in the almost infinite variety of nature's workshop we find such varied conditions that it is mainly a question merely of piecing together into an accordant whole the patchwork of facts presented. Of this much we can be sure, that everywhere in the universe the same materials are present, and the same laws of nature rule, with which we are familiar here. We believe also that processes of evolution and change are everywhere in operation, just as upon the earth. These evolutionary changes we can of course not actually trace throughout their progress, any more than we can cause to pass before our eyes the development of man or the building of the

continents. But in both cases the evidence is there, and only requires ordering and interpretation. Some stars are of immense size, of very low density—much lower in density even than our own atmosphere—and of comparatively low temperature. Others again are smaller, of greater density, and with a higher temperature—changes which we should expect from contraction under the force of gravity. At the other end of the sequence are stars of very small size, but of a density many thousand times greater than anything we know on earth; and again, in the light of modern physics, the picture seems a not unreasonable one. Many of the details are still far from clear, and even the sequence of processes may have to be revised. But tentatively we may assume that individual stars pass in order through the three stages mentioned, our sun being in the central stage, which lasts for thousands of millions of years at least.

Many questions remain unanswered. One of the most insistent is, whence comes the supply of heat which is so prodigally radiated by the sun and the other stars over such long periods. Formerly it was supposed to be produced by contraction under the forces of gravitation. However, with our present knowledge of the periods of time involved, it is clear that this source is entirely inadequate. The conclusion has been forced upon us that the supply of heat must be replenished by the release of internal atomic forces—either by the actual transformation of matter into energy, or by the building up of heavier elements out of hydrogen, the lightest and simplest of the elements, or by some similar process as yet entirely unknown.

Others of the unanswered questions deal with the origin and the ultimate fate of the universe. We think we can trace the history of the stars and the nebulae back to a certain point. What lies before? Did they exist for all time, and if so, in what form? Is the universe running down? Will there came a time when the heat of the stars is dissipated throughout space, and all things are cold and dead? Or is there some as yet unexplained process by which they are rejuvenated, to run through the cycle of change once more? If so, are these processes going on now, or will the change when it comes be catastrophic? Is the universe really expanding, as spectroscopic evidence would lead us to believe? If so, what will

be the end, if any? Is space infinite or finite? If finite, what lies beyond? What do infinite space and infinite time mean? Can we even imagine that we understand such terms?

Such questions are easy to ask, but hard to answer, or even to speculate on. One thing is certain: science will not soon be left without problems to investigate.

Dominion Observatory, Ottawa,
December, 1933.

AN ELEMENTARY APPROACH TO RELATIVITY*

By F. J. Brand

IN this paper I propose to discuss the Theory of Relativity in a very light elementary way. My aim is not to expound principles, but rather to describe some of the earlier sources of the ideas that have been ingeniously embodied into these principles. The Theory of Relativity is an unusual blend of pure imaginative concepts and actual laboratory facts. It has a kinship with nineteenth century geometries in its doctrine that space is curved, finite, unbounded, and it is an immediate acceptance of a physical experiment which permits it to state that the same beam of light will overtake two observers, no matter how large their relative velocities, at the same invariant speed of 186,000 miles per second. These ideas seem a bit absurd. On first thought they scarcely recommend themselves to our ordinary common sense. But after all, they on the one hand are forged according to the needs of modern sensitive physical experience, and on the other hand exhibit behind their superficial oddity a reasonableness and logic that are embedded in their mathematical past. It is this latter phase and character of the ideas that mainly concern me. I begin then with a little history.

There is a postulate in Euclid which stands in a productive relation to Relativity. It is—that through a point only one line can be drawn parallel to a given line. This statement is plain enough and is pictorially satisfactory at least. When examined by a drawing it does seem to describe the behaviour of our straight lines. But mathematicians of the eighteenth and nineteenth centuries were more skeptical and felt that it should be proved as a consequence of the other assumptions made in the Euclidean system. At any rate it was known to be in a different category to the axiom for instance that things which are equal to the same thing are equal to one another.

Gauss made valuable researches into the problem of this parallel

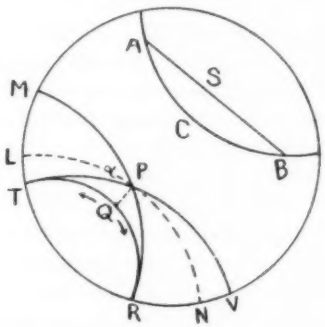
*Read before the Vancouver Centre of the Royal Astronomical Society of Canada.

postulate, but the final solution was due to Bolyai, a Hungarian and Lobatschevsky, a Russian. They worked quite independently of one another and both did the very brilliant thing of accepting all of Euclid's postulates except the parallel one, which they replaced by another, *viz.*, that through a point many lines can be drawn parallel to a given line. This was a contradictory, unnatural attack upon the problem, with a certain frivolous side which it was hard at first to take altogether calmly. But their method justified itself ultimately for two related reasons. It revealed the inner nature of any postulate-concept, and produced a unified geometry which in mathematical significance was a peer of Euclid's. Naïvely Lobatschevsky's postulate seems wrong and Euclid's seems right, but actually both are equally valid because from the point of view of pure logic each leads to equally sensible "truths". For example, Euclid states that the sum of the angles of a triangle is 180° and Lobatschevsky that the sum is less than 180°. Compared absolutely both theorems cannot be true, but within their respective systems, judged solely on the basis of the respective original axioms and the whole body of other consequent theorems both are individually consistent, which is to imply that they are both individually true. For ideal creations such as these geometries are, we have this one legitimate criterion of truth . . . that a theorem should not contradict any other theorem that springs from the same set of assumptions. In point of simplicity Euclid's geometry is superior but there are situations where Lobatschevsky's has the advantage, and fictitious worlds can be devised where Lobatschevsky's is natural and Euclid's inconceivable as Poincaré has shown.

Poincaré's universe illustrates the meaning of the newer geometry in a picturesque way. This universe may be imagined as a sphere of any size within which there are effective variations of temperature from that of tropical heat (say) at the centre to absolute zero at the outer rim. All the beings and objects within this universe are immediately sensitive to temperature changes, growing smaller as they get colder and vanishing completely at absolute zero. If a person journeyed from the centre to a cooler climate his shrinking would be instantaneous and continuous along with all the objects of his environment. Soon, to our outward eye he would appear a

very small person, garbed in a doll's suit and sailing in a ship the size of a toy, but in his own judgment he would still have the same stature as his one-time warmer self; and the ordinary simple test of measurement could not correct this opinion for his inch-tape would have shrunk in a corresponding degree. Finally, if this traveller tried to continue to the frozen rim he would find it impossible to get there, because to him with his infinitesimally small feet and conveyances the space ahead is an infinite extent.

Two mathematical properties of this weird space are curved lines and a non-Euclidean parallelism. Euclid defines a straight line as the shortest distance between two points. This is a serviceable idea and we shall adopt it here. A cross-section of this uni-



verse is drawn in the diagram. Let A and B be any two points between which we want the shortest distance, *i.e.*, the straight line or geodesic as it is called. Mathematically this is proved to be that circular arc ACB which produced would cut the outer rim orthogonally; and superficially this result seems quite plausible when we compare the two tracks ACB and ASB, and recall that a chain along ACB would be warmer and longer than a chain along ASB, since throughout its course it is nearer to the centre. These curved geodesics affect the disposition of parallels. According to Euclid, again, if we (1) take a point Q on a straight line L, (2) take another point P not in the line L, (3) join P Q, and (4) allow Q to travel first to infinity on the right and second to infinity on the left then the two ultimate right and left branches P Q are in one and the same straight line, which is parallel to L—*i.e.*, P Q meets

L at infinity in both directions. This provides a convenient mechanism for exhibiting a parallel line which can be easily applied to our Poincaré universe. In the diagram T Q R is a geodesic; T P V is the ultimate right branch of P Q and R P M the ultimate left branch of P Q. Both these branches meet T Q R at the boundary or the infinity of space and hence are parallel to T Q R, according to our Euclidean scheme. So too is any geodesic through P within the angle α —as L P N. We have here then an actual infinity of "lines" through a point parallel to a given "line"—and accordingly the natural geometry of these inhabitants would be Lobatschevsky's and only the most imaginative mathematicians there would enquire the consequences of restricting parallelism to a single line as in Euclid's case.

There is still another phase to this parallel problem, *viz.*, where it is supposed that no lines can be drawn through a point parallel to a given line. This was worked out by the German mathematician Riemann in a beautiful and profound dissertation in 1854. Riemann's geometry is something new again. It states for example that the sum of the angles of a triangle is greater than 180°, and has different conclusions to those of Euclid and Lobatschevsky wherever the different parallel postulate is employed in the argument. Still, once more, the new theorems are self-consistent and true under the shadow of the original assumptions. The new space is accurately depicted in two dimensions by the surface of a sphere. It folds round into itself, without a boundary. It is finite, measurable, and possible of complete exploration by any two dimensional being who inhabits it. A geodesic is necessarily curved,—the arc of a great circle; and often more than one straight line can be drawn through two points, for example, the meridian lines through the poles of a globe. We must observe that these few properties are given for two dimensional space and are easily pictured because we have a three dimensional sense. But the task of visualizing Riemann's curved space of three or more dimensions is hopeless. We can, therefore, only adopt an abstract perspective and analyse its nature with symbols.

If we are to interpret our own space—the space within an atom, within a room, within the galactic system—then geometry so far provides us with three main patterns that we may use. We

feel from experience with everyday solid permanent things that our space is Euclidean. We know that geometry originated from the study of external objects and naturally expect Euclid's theorems to describe their relationships properly. The whole science of engineering, with its successes everywhere, assures us of the reliability of Euclid's system. Our own rough judgment, reason, and the architecture about us support this ancient upright geometry. It is otherwise, though, with modern physics which has such insight, power and refinement as to make us very diffident about our own crude estimates and prejudices. Suppose we endowed a modern atom with eyes having the same range of vision as our own and let it observe a skyscraper from the gutter. It would not see the solid slender column that we know, but presumably some dazed whirling concretion of particles rising like a vertical section of the milky way from an immense turbulent sea of other particles. Whatever the image, certainly it would be something irreconcilable with our impressions of a rigid substantial structure. The atom would see swift movements and enormous disturbances, varying with temperature and any electric influences near the building, as for instance an active dynamo. It would be a universe of bustle and peculiar behavior, and I do not think its geometry would be Euclidean nor its mechanics those of Newton. But these vast infinitesimal worlds seem to be a big puzzle all themselves. We shall leave them and consider an earlier discovery more closely related to the Principle of Relativity which began to suggest the need for a revision of our physical conceptions.

The Michelson-Morley experiment is well-known. Its purpose was to detect, if possible, the absolute motion of the earth through the ether. The method was to select two light rays from the same beam, and after sending them on equally measured journeys in two different directions at right angles to one another, to watch their times of return to the starting-point. Every swimmer knows that it takes longer to swim 100 yards up stream and down than it does 100 yards across and back. The two light rays are swimmers in the ether stream flowing past the earth. By varying the two right-angled directions it was supposed that at some time one would be going the up direction and the other across. But repeatedly the result of the experiment was a tie. This was very baffling. It was

explained by Fitzgerald and Lorentz by means of a contraction theory, which asserted that all matter was subject to a physical shrinkage in its direction of motion. In this manner the earth would be squeezed up in the direction it was going, just sufficient to compensate for the stiffer course of the up-stream ray. It can be readily calculated that if the length of the one course were "l", the shorter would be $l\left(1-\frac{\mu^2}{c^2}\right)^{\frac{1}{2}}$ where "c" is the velocity of light and "μ" the velocity of the earth through the ether.

In our physical laws we must describe the position of the point considered with respect to some axes, just as a city's position is determined with respect to the equator and the meridian line through Greenwich. It had been assumed that these axes for the physical laws were planted in the ether or among the "fixed" stars, and all phenomena were supposed to be viewed and analysed against some such permanent background. The background didn't reveal itself in the Michelson-Morley experiment, and accordingly the mathematicians began to examine the consequences of referring laws to axes moving uniformly as well as to the heretofore stationary set. We have in Maxwell's theory of electro-magnetism, for instance, groups of differential equations in quantities E, the electric intensity, and H, the magnetic intensity for the point x, y, z, at a time "t". Involved in them is a factor "c", the ratio of the electro-static unit of charge to the electro-magnetic unit, and known to be the velocity of light. If now we take a set of axes whose uniform velocity is "μ" against the supposed ether and whose co-ordinates carry dashes, then we can transfer Maxwell's laws to them readily enough by the proper substitutions. If as is natural and simplest, we take $x = x' + \mu t'$, $y = y'$, $z = z'$, $t = t'$, we find that different laws appear, and "c" the velocity of light, depends upon "μ". Lorentz very ingeniously showed that the laws avoided distortion—as experiments required—if we placed $x = \alpha\ (x' + \mu t')$ $y = y'$, $z = z'$, $t = \alpha\left(t' + \frac{\mu x'}{c^2}\right)$ where α is the expression $\frac{1}{\sqrt{1-\frac{\mu^2}{c^2}}}$ that occurred inverted in the contraction theory above.

Under these more complicated transformations Maxwell's laws retain their first form and "c" remains independent of "μ"—which is what we want. Thus the accomplishment of the invariance of the laws is purely a mathematical problem, and we observe it involved a tampering with the new time unit as well as the spatial unit. We have now a new hybrid, called space-time. This fusion occurred in the last of the transformations above, so that formally it is no longer true that space and time are composed separately of points and instants. By the exigencies of mathematical logic we have been forced to abandon the foundations of the old mechanics.

The new outlook was developed by Einstein by use of the axiomatic method. He cleared away the debris of established conventions and stated flatly that Nature is such that it is impossible to determine absolute motion by any experiment whatever. This is plainly a generalization of the Michelson-Morley result. It implies that physical laws must retain an invariant form for any two reference frames moving uniformly with respect to each other: which in its turn in the light of the descriptive analysis above is equivalent to stating that the velocity of light is constant for all observers. Beginning at this point Einstein constructed his special Theory of Relativity, using the Lorentz transformations. There is, however, a profound difference in Einstein's viewpoint and interpretation of the whole scheme of things. Lorentz required an actual physical compression of matter in the direction of motion, and the motion was taken with reference to an actual ether framework. Einstein illustrated that the contraction is an appearance only, due entirely to the relative motion of the two objects or observers and the fact that the most efficient means of communication are with light signals. The all-pervading ether does not enter his scheme so that an absolute external length has no meaning, for length can only exist as a relation between object and observer. Relationships vary for different observers, and hence time, length, and order vary also and there is no free final adjudicator to offer a standard. It is a relative fluctuating world. The only permanent things in it are the principles or "expressions" of its behaviour, called laws.

In the space-time continuum of four dimensions, all the electromagnetic laws conformed beautifully to the principle of relativity.

Newton's gravitation laws failed to do so. This was a serious breach, for if Einstein's first assumption was correct, no gravitational experiment could expose an absolute motion, and yet, the equations varied from framework to framework. Einstein attempted then to bring gravitation within the scope of the relativity principle and succeeded in 1915 with his General Theory by assuming that space is of an approximate Riemannian character. It is a very daring assumption and implies for the four dimensional space-time continuum all the odd Riemannian properties repeated above. It grants to space-time inherent powers which guide all matter in its career, as though there were individual flexible tracks laid everywhere. A body always selects the easiest, quickest path from place to place—the geodesic or "straight" path through curved space. We know that the course of the earth is a very slightly flattened ellipse, but what we are actually describing is a projection of the earth's path in three dimensional space—a most artificial and unsatisfactory representation of reality. The earth takes time to complete its course and when the variable time is introduced into the mathematical analysis the course is found to be a steady geodesic cruise "straight" ahead through the four dimensional space-time continuum.

It is an interesting outlook and there is good reason for thinking it the right one. Einstein predicted by his new mechanics that the perihelia of the planets would all advance at a rate which varied according to their distances from the sun. In the case of Mercury this had been observed by Leverrier, and the recent measured amount of the advance tallied accurately with Einstein's calculations. For the other planets the movement was too slow and small to be detected. Einstein also made the famous prediction about the deflection of a light-ray in passing through a strong gravitational field, which was substantiated accurately by the observations made in 1919 and 1923 during the eclipses of the sun. There are other tests which so far have been unsatisfactorily applied because of their difficulty. But up to the present the experimental evidence is in the theory's favour. There are blemishes in its form which will have to be corrected by further analysis and a modified geometry, but even as it stands it is the most comprehensive and unified body of principles and results in the entire range of scientific thought.

University of British Columbia.

REVIEW OF PUBLICATIONS

Mathematical Tables, Volume III; Minimum Decompositions into Fifth Powers, by L. E. Dickson. The British Association for the Advancement of Science, London, England. Quarto. Price 10 shillings.

An integer n can be expressed in various ways as the sum of the fifth powers of integers; there will be a number N, depending on n, such that n is expressible as the sum of N fifth powers and no fewer. Any expression of n as the sum of N fifth powers is called a minimum decomposition into fifth powers. This book of Dickson's consists of a table, occupying about 250 pages, giving the actual minimum decompositions of all numbers up to 125,000 into fifth powers, supplemented by a second table of about 120 pages giving the values of N for all numbers from that stage up to 300,000. From the information given it is a very simple matter to obtain the decompositions of the second set of numbers.

The tables are reproduced from typewritten copy; thus the expense of printing is avoided as also are the errors that might have arisen in the setting up of type. The arrangement is very clear and extremely concise; the general appearance of the page is not unpleasant. The only error that the reviewer has noticed, while checking a very small number of the decompositions, is one which could cause no trouble—the entry opposite the number 84,197 should obviously be 14 and not 114.

The astronomical reader may perhaps wonder as to what purpose is served by these tables and why a man of Dickson's calibre should spend his time in supervising their construction. As regards the second question it may be stated that, if it were not for a method devised by Dickson for finding a minimum decomposition without finding all decompositions, the amount of calculation involved would have been increased enormously; as regards the first question the answer is that the Theory of Numbers is, to a large extent, an empirical science and the only one based on absolutely accurate data, the data consisting of tables such as these.

A few observations will substantiate this last remark. One is led by a general rule to consider the number 233 for which $N=37$, the minimum decomposition being given by $233=6.2^5+31.1^5$; every other integer in the table decomposes into at most 32 fifth powers, and those from 191,264 onwards require at most 15. From the asymptotic theory of numbers it is known that $N(n)\leq 35$ for all sufficiently large n. By combining another result of this theory with the information given by these tables Dickson has been able to show that $N(n)\leq 41$ for all n's. It is almost certain that an extension of these tables would result in the reduction of the number 41 to the final number 37, and that the tables themselves will suggest to an observant investigator a substantial improvement in the value of the number a such that $N(n)>a$ for an infinity of integers n.

In conclusion attention should be drawn to the reasonable price of the volume; its appearance was made possible by a bequest from Lt.-Col. A. J. C. Cunningham, whose interest in the Theory of Numbers is well known.

W. J. Webber.

L'Astronomie Egyptienne, by E. M. Antoniadi, 157 pages, 6¼ x 8¼ in., 7 plates and 50 figs. Paris, Gauthier-Villars, 1934, price 40 frs.

Ancient Egypt has a great fascination for many people. Its pyramids and temples; its tombs and mummies; its papyrus rolls and hieroglyphics, containing records of the achievements of the pharaohs who lived thousands of years before our era; these and numerous other peculiar features, continually excite our wonder and admiration. Just what were the scientific achievements of the ancient Egyptians, especially in medicine and astronomy, is an important and attractive question but it can be attacked successfully only by one who is both a scientist and a scholar. The author of this book seems to be qualified for the task.

M. Deslandres, honorary director of the observatories of Paris and Meudon, writes the preface. He tells us that M. Antoniadi was born at Constantinople, of Greek extraction, although he has been a naturalized French citizen for years. As a youth he had a

thorough grounding in Greek and Latin, and he is profficient in other languages also. He is thus able to read most of the sources of information in the original language.

"There exists no work", says the author, "which treats in detail the different branches of Egyptian astronomy, the most ancient and the most precise, the most learned and the most philosophic of all before that of Greece". This he endeavours to supply. In order to procure material for the work he copied out and translated all the important texts of the Greek writers on Egyptian science which he could find in the National Library in Paris.

The titles of the seven chapters are: Generalities; Greek philosophers and Egyptian priests; astronomical divinities and ideas on the universe; the Egyptian constellations; the sun, moon, planets and comets; the earth and the Egyptian calendar; the astronomy of the great pyramids.

It is impossible in the space available here to analyze these chapters, but it may be stated that the various branches of the subject are treated with thoroughness and clearness, and exhibit a breadth of information on the history of Egypt. A valuable feature of the work is that, in presenting his story, M. Antoniadi uses largely the very words of the original source (in French, of course) and gives in footnotes the precise place to find what he quotes.

The present writer knows of no other work which contains such a complete treatment of Egyptian astronomy. There is a wide interest in this subject among English-speaking people and an edition in English would surely have a good sale. Perhaps M. Antoniadi would undertake to put it into English. He is well able to do so.

C. A. C.

METEOR NEWS

Observations relating to meteors and meteorites are cordially invited.

Bright Fireball, January 26, 1934

A fireball of unusual size and appearance was observed on January 26 at about 10.10 p.m. E.S.T. from several towns in the neighbourhood of Oakville in southern Ontario. It appeared high in the northwest and fell towards the north, growing in apparent size until, according to one report, it had an apparent diameter equal to five times that of the sun. The fact that the sky was covered by light clouds at the time probably diminished considerably its apparent brightness and will make the computation of its true path more difficult. Requests for observations have been circulated in the daily press and it is hoped that all those who observed this phenomenon will write in to this department of the Journal, giving full particulars of the observation.

Incidentally, in this connection, it is well to remember what information is essential in reporting a bright meteor. The most important points may be included under a dozen headings which can be divided into four groups of three each, thus facilitating their commitment to memory. They are listed below:

Information to be Given in Reporting a Bright Meteor

I. The Observer:	name	place	time
II. Position of Meteor	azimuth	altitude	slope
III. Appearance of Meteor:	brightness	colour	speed
IV. After effects:	train duration	train motion	sounds

In the first group comes the name of the observer, with which should be recorded his address. The exact place he was located when the meteor was observed should be given and the more accurately this is reported the better. The same holds for the time and date of the phenomenon.

The next group concerns the location of the meteor in the sky. The azimuth is the angle between the meteor and the N, S, E, or

W points. This, where possible, should be given for the beginning and the end of the path, as also should the altitude. The latter quantity is the apparent distance above the horizon, the horizon being considered 0, the zenith 90. The slope is the angle the meteor's path makes with the horizon. If the position of the meteor among the stars is plotted, azimuth, altitude, and slope need not be given.

The total brightness of the meteor should be compared to such standards as the sun, moon, Venus, Sirius, etc. Any bursts or changes in brightness should be noted as well as the shape and size of head. Along with colour should be described colour changes. The speed includes the length of time the meteor was visible, whether it seemed fast or slow and any changes in the direction of motion.

Under after effects come observations of the enduring train, both as to duration, appearance and motion. Accurate plots at minute intervals of the position among the stars of an enduring train are extremely important. If no enduring train was observed after the meteor disappeared, this fact should be clearly stated. If sounds are heard, their nature and the time elapsing between the meteor's appearance and the arrival of the sounds should be recorded.

Meteor Photography in Alabama

Mr. Alfred Boyles of Ensley, Ala., has, during 1933, made a very fine record in astronomical photography. During the year he has made 91 exposures with direct cameras, totalling 105.4 hours exposure time. Four meteors were photographed, one of these, a Leonid, being simultaneously photographed from two stations. Many of the plates were guided and those seen by the writer show images of excellent quality, even for three-hour exposures. Mr. Boyles also fitted out and adjusted his own meteor spectrograph and used this at the time of the Leonid and Geminid showers but poor weather and few meteors minimized his chances of success in these cases. It is to be hoped that others in different parts of the continent will follow Mr. Boyles' fine example. Photographic observations have an accuracy impossible to attain in visual work and it is greatly to be desired that our all too scanty photographic data should be increased.

THE GIACOBINI METEORS

With reference to the meteoric shower observed in Europe on October 9, 1933, it may not have come to the attention of everyone that Dr. A. C. D. Crommelin predicted such a shower over ten years ago. On page 429 of "Splendour of the Heavens" he says: "Another comet of interest is that of Giacobini . . . this is one of the comets that may be expected to give a meteor shower, owing to its orbit passing near the Earth's position in October".

THE LEONIDS OF 1899

An interesting account has been received from Mr. J. W. Rowe of Toronto concerning a meteor shower which he observed some 34 years ago. Mr. Rowe was at that time stationed on a warship which was in Japanese waters. One night near the end of 1899 or beginning of 1900, when the ship was lying in some port between Hongkong and Yokohama, he went on deck shortly after midnight. The night was clear and his eye was attracted by large numbers of shooting stars moving in all directions. Mr. Rowe could only observe one-third of the heavens and he estimates that he saw 50 or 60 meteors per minute. He believes that he was the only man on deck at that hour and states that unfortunately the phenomenon was not recorded at the time and so the above information is all he can vouch for with certainty. There seems little likelihood of fixing the date or place more exactly but it is just possible that these meteors were the Leonids of 1899.

P. M. M.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

Waterspouts on Lake Ontario

D. Carter, wireless officer on the *Cyclo Warrior*, has reported to the Meteorological Office an unusual occurrence of waterspouts on the morning of October 18 at the eastern end of Lake Ontario. According to Mr. Carter at the time the first spout appeared the wind shifted from southeast to a gentle northerly breeze. The cloud cover then consisted of two layers of thick round-edged dense gray clouds. A dark point in the lower cloud crept slowly downward to the water where a whitish mass of spindrift rose to meet it. The column grew larger and darker lasting some 30 minutes. At about 7.10 a.m. a second smaller waterspout was formed which lasted only 10 or 15 minutes. Both waterspouts were bent about their middle point at a slight arc towards the east. The barometer at nearby land stations was reported high and steady at 30.05 in. with air temperatures about 45° F.

W. E. Hurd of the U.S. Weather Bureau has collected reports from every source of waterspouts and has records of 20 waterspouts on Lake Erie, 4 on Lake Ontario and 1 on the St. Lawrence River. Further reports on waterspouts, if possible accompanied by photographs, are much desired by the Meteorological Office.—Andrew Thomson, Meteorological Office, Toronto, Ont.

The Velocity of Light

The problem of determining the velocity of light received much consideration from the late Professor A. A. Michelson. His first experiments were made in 1878 while he was a young officer on duty at the U.S. Naval Academy at Annapolis. Other measurements were made by him a few years later at Washington in collaboration with Newcomb and after that at Cleveland in 1882-3. Fifty years later he returned to the problem.

Using stations on Mount Wilson and Mount San Antonio, near Pasadena, 22 miles apart, he made a series of experiments in 1924, 1925 and 1926. The final result announced was that the velocity

in a vacuum was 299,796 kilometres per second. From several series of measurements the results differed less than one kilometre per second. During the experiments there were certain unexplained variations in the velocity obtained which exceeded considerably the experimental errors of measurement. One of these had a period of 14¾ days (half a lunation) and the other a period of about a year. After a while these two variations disappeared and it is believed they were due to experimental sources, not to any change in the velocity of light.

In these experiments of course the velocity in air was measured, and then the retarding effect of the air allowed for, 67 kilometres per second being added to the velocity in air to obtain the velocity in a vacuum.

In order to eliminate the uncertainty due to this air allowance, Michelson undertook to measure the velocity in a pipe about a mile long from which the air could be exhausted. While engaged on this task he died, but the great experiment has been completed by Dr. F. G. Pease of the Mount Wilson Observatory and Mr. Fred Pearson of the University of Chicago, who had actively assisted in the previous experiments. After overcoming numerous difficulties the velocity obtained is 299,774 kilometres (186,780 miles) per second. This is 22 kilometres less than the result from the 1926 measurements, or 7/1000 of one per cent. lower.

It has been suggested that the velocity is slowly diminishing and a table of resuls given in *Nature* in 1927 by Gheury de Bray gives some support to this idea; but the determinations made in the last eighty years have not been sufficiently accurate to warrant this conclusion. We have yet no reason to abandon our belief that the velocity of light in empty space is a fundamental constant of nature.

Another Planetarium for the United States

The way is now clear for the American Museum of Natural History, New York City, to secure a planetarium, which it has had on its list of wants for some years. Charles Haydon has made a gift of $150,000 to the Museum for a Zeiss planetarium and also a planetarium representing the solar system on scale models. The cost of a suitable building will be defrayed from a bond issue of

$650,000 to be purchased by the Reconstruction Finance Corporation. This will be repaid from income from admissions although at certain times school children will be admitted free. The planetarium is to be ready in the spring of 1935. The dome will have a diameter of 75 feet and will seat 750 people.

This will be the third planetarium in the United States, the others being in Chicago and Philadelphia. Germany has twelve, Italy two, Austria, Russia and Sweden one each.

Congratulations to Dr. Clyde Fisher, curator of astronomy and education in the Museum, on the success of his efforts!

Glass Discs for Large Mirrors

Astronomers are delighted with the news that the disc for the 200-inch Mount Wilson reflector will be poured at the Corning Glass Works within a month. This company must be congratulated on the rapid progress it has made in the production of large discs since the experiments on fused quartz were abandoned. A special type of Pyrex glass has been developed for the purpose. For crown glass the coefficient of linear expansion per centigrade degree is about 0.0000090, for ordinary Pyrex the coefficient is 0.0000032, while for the new type it is about 0.0000025. Thus the change of shape of a mirror with the new material, due to a change of temperature, will be much smaller than with other kinds of glass.

It may be of interest to give some facts relating to the disc for the 74-inch telescope of the David Dunlap Observatory. The inside diameter of its mould, which was made from very refractory bricks, was 76¾ inches and the bottom was made spherically convex so that the lower face of the glass disc should be concave, the disc being one inch thinner at the centre than at the edge. The pouring took place on June 21 last.

Some 75 tons of the special Pyrex had been melted in the furnace, and the mould, under its bee-hive covering, was about 30 feet away. It was kept at about 800° C. When the viscous liquid was ladled out the temperature at the back of the furnace was about 1500°; at the front, 1480°. A ladle-full was dipped out, run across on a trolley, and poured into the mould. Not all ran out of the ladle and the remainder was dumped on an iron plate near by. After

the mould had been filled its temperature was raised to 1250°, at which it was kept for 4½ hours. By this time the liquid had become homogeneous throughout and the bubbles in it had come to the top.

The heat was then turned off and the temperature fell to about 800°. The disc was now placed in the annealing kiln which was set at 475° and the disc fell to this. Next it was brought up to 530° and held there for nine days. This was the "soaking" process. After this the cooling began, first at the rate of 2-2/3° a day until 380°, and then the rate was increased to 18° a day. At the end of three months the disc was removed from its mould and tested for strain by polarized light. It was found to be satisfactory. It was then shipped to Newcastle, England, to be made into the mirror. The concave surface was first rough-ground and then surplus material was ground from the back.

A few days after June 21 the 120-inch disc was poured. This is for a plane mirror to be used in testing the 200-inch mirror. The 120-inch disc has now been removed from its mould and is declared very satisfactory. It is almost free from strain, is perfectly clear and almost free from bubbles. Previous experimental discs, of diameters 30 inches and 60 inches, as well as this disc, have ribbed backs, honeycombed in appearance, in order to reduce the weight. The 200-inch disc will also have a ribbed back. It will be about 30 inches thick. It will be allowed to cool below 500° and will be kept until the temperature is uniform throughout. On account of the thick non-conducting mould this stage will require four months, and the subsequent cooling stage will require about the same length of time.

During the World War when the European supply of optical glass was cut off the problems in the annealing of glass were solved by the Geophysical Laboratory of the Carnegie Institution, of which Dr. Arthur L. Day is director. The present writer wishes to compliment the Corning Glass Works on their admirable work and would pay tribute to Dr. G. V. McCauley, who is immediately in charge of the production of these discs.

ASTRONOMY AND CIVILIZATION

It has been said (by an astronomer) that we may judge of the degree of civilisation of a nation by the provision its people make for the study of astronomy. "When the pursuit of astronomy for its own sake is cultivated, we have a recognition of the supreme worth of scientific method. At this stage in the world's history it is but too clear that a nation can only progress when it moves under the influence of the scientific spirit and when it is recognised that the chief value of scientific method and accurate knowledge lies, not in their worship by the intellectual few, not in their applications to industry, but in their influence upon the daily life of the people."

The astronomers of the Middle Ages did a work of inestimable benefit to humanity when they rescued a large field of phenomena from the empiricism of their day and showed that law and order reigned in the movements of the heavenly bodies. The regeneration of physical science which followed the revival of learning altered entirely the prevalent conception of the universe; man ceased to be the centre round which the whole creation moved and the phenomena of nature were no longer interpreted as existing solely for his sake; the eclipse, the comet, the meteor, and the tempest were not supernatural interventions intended to warn him, direct his conduct, and punish his infractions of the moral law. Astronomy played a leading part in the liberation of mankind from the intellectual torpor which characterised what are called the Dark Ages, and by substituting law for chance laid firmly the foundations on which all the splendid structure of modern science rests.

In this context an incident in the life of President John Quincy Adams may be recalled. The laying of the corner-stone of the Cincinnati Observatory in 1843 was considered by him, in his seventy-seventh year, to be worthy of a hard trip by rail from Massachusetts to Buffalo, by lake steamer to Cleveland, by four days of miserable canal boat to Columbus and then on to Cincinatti. Adams appreciated to the full the importance of the occasion. He had come a long journey—to quote his own words—"To turn this enthusiasm for astronomy at Cincinnati into a permanent and persevering national pursuit, which may

extend the bounds of human knowledge and make the country instrumental in elevating the character and improving the condition of man upon earth."

America has gone very far since the day of President Adams; from small beginnings it has worked its way into the forefront of the astronomical world; in many of its universities the subject of astronomy receives marked attention; in no direction has the munificence of its citizens been better displayed than in founding observatories and providing them with the best equipment possible. E. G. Hogg in *Astronomical Notes* of the New Zealand Astronomical Society.

C.A.C.

MEETINGS OF THE SOCIETY

AT TORONTO

October 10, 1933.—A regular meeting was held at 8 p.m., Mr. J. R. Collins in the chair.

The lecture of the evening was delivered by Mr. F. T. Davies, on the subject, "International Polar Year, and the Canadian Expedition to Chesterfield Inlet". It has been agreed that scientific investigations of the north polar regions can be best carried out by the various countries interested working together and concurrently at many stations in the Arctic, for a period of a year. The first International Polar Year was from August 31, 1882, to August 31, 1883; and the second ended in August, 1933. During the past year twenty nations sent parties to the Arctic with a definite programme to study (1) Meteorology; (2) Terrestrial magnetism; (3) Atmospheric electricity; (4) The Aurora. Canada established four stations, the largest being at Chesterfield Inlet, with a party of four: Mr.F.T. Davies, Dr. B. W. Currie, Mr. S. T. McViegh, and Mr. J. P. Rea. The party arrived in August in 1932, set up comfortable quarters, and made almost continuous observations for a year. The meteorological studies included recording the temperature, atmospheric pressure, humidity, sunshine, ground temperature, and winds. For the upper air two methods were used: (1) Balloons were observed from theodolites for wind velocity and direction. (2) Meteorographs, carried by two box kites to altitudes of about one mile, recorded temperature pressure and humidity. There were 496 balloon flights, some very long and one probably a world record. The reeling-in of the kites was no small part of the party's labours. The electrical section of the work was directed by Dr. Currie, earth currents were recorded, using four electrodes one mile apart, and showing rapid changes of great magnitude. The magnetic observations, in charge of Mr. Davies, required a special hut, containing magnetic instruments for making automatic and continuous records of the variations in the earth's magnetic field; also with a Kew magnetometer the absolute value of the horizontal component of the earth's field was measured. The magnetic changes corresponded very well with the changes in the earth currents. The aurora was studied during the dark part of the year from two stations 20 miles apart. Continuous pictures were taken from both stations to determine the height of the aurora. Most of the auroral displays occurred in the south sky, since the maximum band is near Churchill, which is about 450 miles south of Chesterfield Inlet. Mr. Rea heard the aurora on one occasion like the rustling of silk, but the other members of the party did not detect any noise. Since the lower limit of the aurora is about 60-70 km., scientists entertain some doubt as to its audibility. Sergeant White, of R.C.M.P. at Chesterfield Inlet, who has been 20 years in the Arctic, reports that he has heard the aurora several times.

The calculations of the year's work are not yet complete. During the lecture

Mr. Davies showed many pictures depicting Eskimo life, and various phases of the work of the party at Chesterfield Inlet. The Polar Year of 1882-3 advanced scientific knowledge of the north regions, and we eagerly look forward to the results of this second polar year.

Mr. Gray tendered to the speaker the thanks of the audience. The meeting adjourned.

October 24, 1933.—A regular meeting was held at 8 p.m. There were 21 persons elected to membership, as follows:

Mr. L. A. S. Dack, Mgr. Bank of Commerce, King and Jarvis, Toronto.
Miss C. L. McLean, 105 Bond St., Toronto.
Miss F. J. Gerry, 60 Oriole Gardens, Toronto.
Miss A. Marion Fox, 257 Jarvis St., Toronto.
Mr. T. C. Wood, Royal Bank Building, Toronto.
Mr. A. J. Boyce, 761 St. Clair Ave. W., Toronto.
Mr. B. J. Topham, 105 Regent St. W., Toronto.
Dr. C. D. Parfitt, Calydor Sanitorium, Gravenhurst, Ont.
Rev. A. Gauthier, S.J., College des Jesuits, Sudbury, Ont.
Mr. G. T. Solomon, Brighton, Ont.
Dr. L. H. Cretcher, Mellon Institute, Pittsburgh, Pa.
Mr. W. A. Rains, 35 LaPorte St., Quebec, P.Q.
Dr. R. E. Macdonald, Rossland, B.C.
Mr. W. Howes, 241 Court Square, Parkesburg, W. Virginia.
Mr. T. Bollinger, 2916 Frankfort Ave., Louisville, Ky.
Mr. F. Prencil, 205 Caton Ave., Joliet, Ill.
Mr. L. S. Gessler, 1147 East 14th St., Brooklyn, N.Y.
Mr. J. Homer Hough, 244 Gerona Ave., San Gabriel, Cal.
Mr. F. Britton, 8041 S. Peoria St., Chicago, Ill.
Mr. A. Williamson, Monticello, Arkansas.
Mr. Cyrus F. Fernald, Wilton, Maine. Life Member.

Mr. J. R. Collins spoke of the recent loss to the Society of one of its most esteemed members, Dr. D. B. Marsh, whose work in astronomy was so widely known.

The predictions of phenomena were discussed by Mr. F. L. Troyer. Mr. Whitehouse reported that a very large meteor, which fell from the vicinity of Ursa Major, was seen on September 24, 8.40 p.m. A short review of the planet Jupiter was given by Mr. G. Hepburn.

The lecture of the evening was given by Mr. A. R. Hassard, K.C., on "Summer Observations". Mr. Hassard suggested that the study of astronomy should be an effective check on the astrologer, and his foolish prophecies. On May 15 there was a very prominent solar halo which lasted from 12 noon to 3 p.m. The rings were very bright having a golden colour inside and a deep orange on the outside, the whole circle having a diameter of 40° to 50°. Mr. Hassard then spoke of the conjunction of Jupiter and Mars which occurred on June 4. On August 16 the speaker observed a fireball at Bath, on the Bay of Quinte. It fell in the western sky, being very brilliant for 7 to 8 seconds, then brightened more

and disappeared, leaving a faint streak. No sound was heard. Mr. Hassard concluded with a few remarks on the appearance of the moon and sun, and of the value of astronomy to aviators.

November 7, 1933.—The meeting was held in the usual place at 8 p.m. Mr. R. A. Gray in the chair.

Three were elected to membership:

Mr. George Nixon, Oakwood Collegiate, Toronto.

Mr. W. E. Knowles Middleton, 315 Bloor St. W., Toronto.

Dr. Hubert Slouka, Astronomer in charge, University Observatory, Prague, Czechoslovakia.

Mr. F. L. Harvey, under "Planetary Discussion", gave a full description of the physical condition of the planet Saturn, its meteoritic ring system, and its satellites, illustrated by a number of lantern slides. Mr. Harvey outlined the knowledge of the planet that has been made possible since Galileo's telescope in 1610 revealed what at that time was thought to be its impossible, its rings. The stability of the rings and the low density of the body of the planet itself were particularly emphasized.

Dr. Millman, who was present, in answer to a query with reference to the white spot that has recently developed on the surface of Saturn, stated that with the six inch aperture telescope, they had not been able to identify the spot.

Mr. F. L. Troyer then gave an address on "Shooting Stars, and how the Amateur Astronomer may assist in observing them." Almost a century ago meteors, or falling-stars were looked upon by scientific men as an electrical phenomenon, of unknown cause, manifesting itself in the atmosphere, but in this same year in which a Century of Progress in Science, Industry and the Arts is being celebrated in Chicago by a great World's Fair, astronomers are also entitled to commemorate a century of progress in the development of meteoric astronomy, for it was not until after the great Leonid meteor shower in the year 1833 that the science of meteoritics really had its beginning, although some thirty or more years previous to that event, two students of the University of Göttingen, Messrs. Brandes and Benzenberg, had plotted the trails of coincident bright meteors from two stations separated by a few miles, and, using a method of triangulation almost identical with that used today, calculated the heights of beginning and end points of the meteor in the atmosphere, and from its duration of flight, knowing the length of its passage, found its real velocity. Their results are still regarded as very accurate. Meteors are not stars which change their places in the celestial dome, as popularly supposed, but are produced by the combustion of small pieces of matter which pass into the earth's atmosphere, and because of the heat developed in their passage through the air, are burned up, causing the brilliant streak of light which we see. Several of our most spectacular meteor showers are produced by material left behind after the disintegration of comets, but many meteors are probably visitors from interstellar space drawn towards the sun, and then towards the earth itself by gravitational action. The cometary meteoric material revolves around the sun in orbits similar to those of the planets, although much more elliptical in shape, and a meteor shower is produced each year when the earth in its orbit intersects one of these meteor swarms.

In view of the fact that the week of November 12-18 would bring the possible return of the great Leonid shower which provided such a spectacular display in 1799, 1833 and 1866, Mr. Troyer made an appeal to amateur astronomers to make all possible observations of meteors during that period, and explained the methods to be used in systematic observing. The most important prerequisites, he explained, in addition to a clear sky, which this year is improved by the absence of moonlight, are first, a station with a clear horizon free from fog and the glare of city lights; secondly, a good star map for plotting, record blanks and a flashlight; and thirdly, as an aid to greater speed and accuracy in plotting the meteor trails, a fairly good acquaintance with the constellations. Reports from amateurs, not only the shower, but at any time, and preferably, for fairly long periods, and always during watches of at least a half-hour; also accurate observations of the paths and directions of sporadic fireballs at all times, are of considerable value to the professional astronomer, who himself can rarely devote much of his time to this important branch of astronomy.

Mr. Troyer explained that no experience in the work, and no technical knowledge or scientific instruments are required for observing meteors.

G. HEPBURN, *Recorder.*

ERROR IN A. H. MILLER'S PAPER IN THE JANUARY ISSUE

By an error in engraving Fig. 1 (page 2) and Fig. 7 (page 13) were reversed right to left. Readers are requested to bear this in mind in reading the text.

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